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Performance Analysis of Switched-Sector Antennas for Indoor Wireless LANs

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Abstract

Given the potential market for wireless LAN (WLAN) technology, capacity within the available 2 and 5GHz frequency bands is likely to fall short of market demands. Multiple-sector antenna arrays are known to be able to provide capacity enhancement by means of interference reduction through spatial filtering. In this paper, the performance of an eight-element circular array acting as an Access Point (AP) in indoor wireless LAN environments is analysed. Spatial-temporal channel data used within the analysis was obtained from physical measurements within numerous indoor environments using a state-of-the-art wideband vector signal analyser. Performance analysis of the array employing a switched-sector controller within Hiperlan/2 standard is appraised in terms of carrier-to-interference (C/I) ratios. Results show that an isolation of up to 15dB can be achieved between the two polarisations by means of using an antenna array at the AP. It is shown that 54% of the time, 2 users per timeslot can be supported by the system.

I. INTRODUCTION

Indoor Wireless Local Area Networks (WLANs) provide a complementary technology to 2G and 3G cellular systems, in order to achieve 'Any Where, Any Time, Personal Communications'. WLAN systems combine data connectivity and user mobility, as well as offer high-speed wireless connectivity. Today, WLAN standards such as Hiperlan/2 (H/2) and IEEE802.11a offer multimedia services including video, audio and conventional data services within homes and businesses. With their ability to support multiple transmission modes, the two standards are able to support data rates of up to 54Mbps.

Given that future WLAN networks will support high bit rate services such as multimedia applications, space-time signal processing is now regarded as a core element within new system deployments. It is envisaged by those involved in wireless system design [1] that space-time processing in the form of adaptive or smart antennas, as well as adaptive interference cancellation methods, offer sufficient improvements in user capacity as and throughput, thus meets the market needs.

Within the H/2 WLAN standard, Spatial Division Multiple Access (SDMA) can provide an additional multiple access overlaying the existing TDMA structure. SDMA techniques aim to provide further capacity improvements by means of

re-using time-slots for a different user that has suitable spatial separation from the primary user.

To date, researches addressing the performance of antenna arrays have mostly been based on Uniform Linear Arrays (ULAs). Numerous researchers [2][3] have shown that these arrays, combined with novel space-time processing techniques, are able to provide capacity enhancement, range extension and interference reduction in both indoor and outdoor wireless communication systems. These antenna arrays are, however, confined to cover a sector of the azimuth plane (nominally 120°). In contrast, circular arrays are able to provide full 360° azimuth coverage. However, limited amount of work has been done so far on this particular type of antenna array.

This paper describes the use of a state-of-the-art wideband vector channel sounder (Medav RUSK BRI), interfaced to an eight-element circular array, operating in indoor environments at 5.2GHz. Performance analysis of the circular array is appraised in terms of Wireless Local Area Network (WLAN) standard, Hiperlan/2, using the measured spatial and temporal channel responses.

II. TECHNICAL OVERVIEW

Reference [4] provides a general overview of smart antenna array applications on mobile communications. The Smart antenna technology considered in this analysis consists of a single omni-directional antenna used at the mobile terminal (MT) and an array applied at the Access Point (AP) site. In the uplink, this configuration is termed "Single Input Multiple Output" (SIMO), a system supported by the H/2 standard. The architecture facilitates the support of multiple channels within the same frequency band and timeslot. The benefits of Smart antennas for cellular architectures are further discussed in [5]. Channel measurements and related post-processing presented here indicate that a multi-sector AP can offer improved spectral efficiency within H/2 by means of spatial filtering.

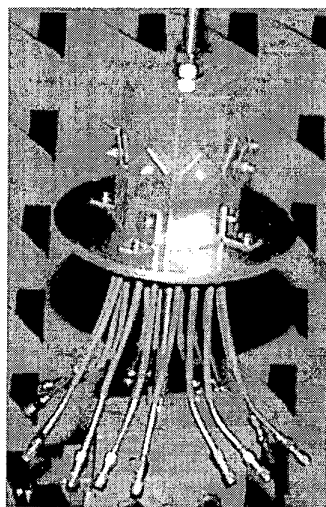
A. Circular Array

The H/2 standard supports a maximum number of 7 sectors at the AP. However, the array developed in this analysis consists of eight dual-polarised patch antenna elements (Fig.1), for the sake of convenience. Thus, the analysis in this paper has utilised the full eight elements,

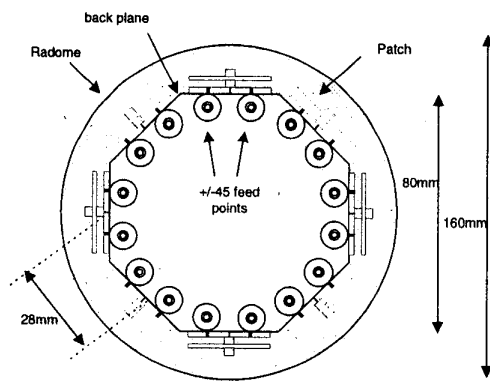
although further post-processing can be applied to the 7-element case.

Each patch is mounted at 45° in order to generate $\pm 45^\circ$ polarisations, arranged on one side of an octagonal metal ground plane. These elements are spaced at $\lambda/2$ apart from the adjacent elements and optimised to operate at a carrier frequency of 5.2GHz. Each element has a 1dB bandwidth in excess of 120MHz.

The individual 3D radiation pattern of each element has been measured in an anechoic chamber using a Wiltron Vector Network Analyser. The array can therefore be readily analysed for switched-sector deployment, using representative element patterns. Fig. 2 shows an example element pattern, where it is seen that there is an isolation of at least 10dB within the 3dB beamwidth between the two polarisations.



(a)



(b)

Fig.1. Circular array employed for performance analysis: (a) Plan view; (b) Side view

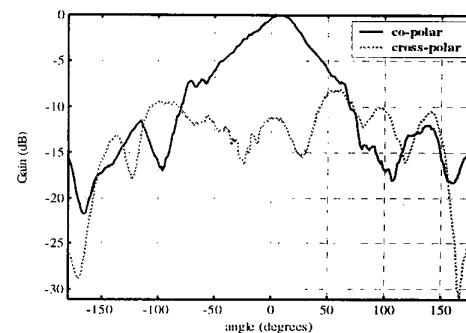


Fig.2. Sample Element Pattern

Although the analysis presented in this paper concerns one polarisation only, this result shows that a further capacity improvement may be achieved by using both polarisations. The element pattern also demonstrates a 12dB front-to-back isolation for each individual element.

B. Measurement System

The channel sounding equipment used for the indoor measurement campaigns described here was the Medav RUSK BRI Vector Channel Sounder [7]. The measuring system employs a periodic multi-tone test signal with measurement bandwidths of up to 120MHz.

The transmitting unit employed a sleeve dipole antenna, with an input power of +27dBm, centred at 5.2GHz. At the receiving end, the circular array described above is interfaced to the channel sounder through RF circuitry consisting of a bandpass and low pass filter as well as a low noise amplifier unit.

A fast multiplexer was used to switch between elements of the array in turn. The received RF signals are down-converted into 80MHz IF signals and sampled at 320MHz. Fig. 3 illustrates the receiver configuration.

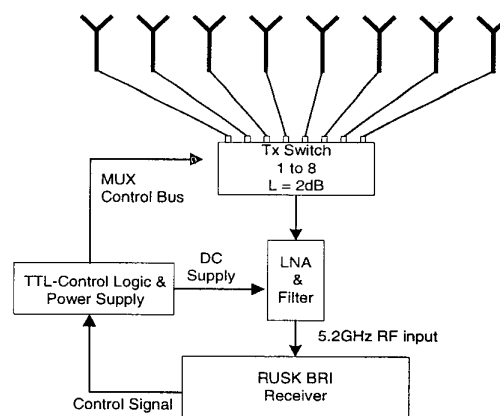


Fig.3. Receiver array configuration

The RUSK BRI records the Channel Impulse Response (CIR) observed at each array element in rapid succession, therefore full 'vector snapshots' of the channel can be recorded across the array within the channel coherence time. The resulting data is converted to the frequency domain and stored on the hard disk for further post-processing.

Measurement coherence was assured through the use of aligned and stabilised Rubidium referenced clocks at the transmitter (Tx) and receiver (Rx). A back-to-back system calibration also accounted for any amplitude or phase distortions in the hardware.

C. Measurement Setup

Channel measurements were performed within the coherence time of the radio channel (estimated well to be $\approx 30\text{ms}$), in order to allow the temporal variation of the channel to be examined in conjunction to the Hiperlan/2 frame period specification [6].

The RUSK BRI measurement parameters were set to 10 consecutive SIMO snapshots within each Fast Doppler Block (FDB) in order to fulfil the coherence time requirements ($\approx 30\text{ms}$). Each snapshot contains 8 consecutive CIR corresponding to each channel. An excess delay window of $3.2\mu\text{s}$ was chosen, yielding 385 frequency fingers spread across the bandwidth.

An extended time grid of 10.240ms between FDBs was used so that some "short-term" variations due to moving people etc. could be followed. The test signal configuration is illustrated in Fig.4. 763 FDBs were taken for each measurement, giving a total measurement time of 7.813s . This allows short-term and long-term channel variations to be followed.

Measurement trials were performed in two buildings at the University of Bristol, including a range of environments such as traditional and modern office accommodations, laboratory space, hallways, and entrance foyers. A variety of scenarios included quiet and busy periods, line-of-sight (LOS) and non-line-of-sight (NLOS). The antenna array was mounted at a height of 2.85m at locations considered representative for a WLAN AP. Measurements were taken while the transmitter was stationary.

III. SWITCH SECTOR PERFORMANCE ANALYSIS

At present, low complexity techniques such as a switched-sector approach are favoured in smart antenna deployments in Hiperlan/2. This is a basic technique used in smart antenna signal processing, where no array processing techniques are employed. The technique depends solely on the individual element radiation pattern. As can be seen in Fig.1, each element forms a beam in a direction perpendicular itself, with a 3dB beamwidth of 50° .

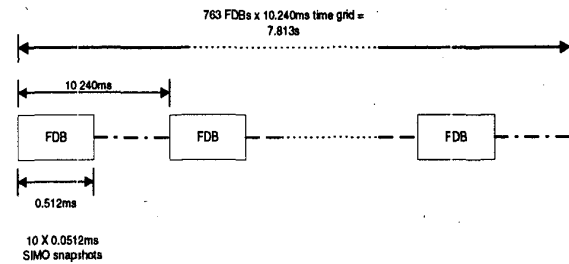


Fig.4. Received signal structure.

Signal enhancement may be achieved by selecting the array element with the highest receive power. Interfering signals impinging from other directions are suppressed provided they are located at a sufficient angular separation from the desired signal.

This section presents some examples of the initial results obtained from the multi-user characterisation channel measurements. Performance of the array is compared to that of an omni-directional antenna employed at the AP, in order to establish a baseline.

Initial post-processing was performed assuming a simple system model, with no power control employed and all MTs contained within a single AP cell. Without power control, however, the distance between the AP and each MT largely influences C/I. The model is therefore extended to employ a power control mechanism that normalises the received power at the AP to the lowest level of received power, thereby eliminating the near-far effect. In this case, C/I is purely dependent on the level of isolation provided by the element patterns.

The analyses presented in this section are based upon channel measurements performed in an indoor modern office environment at the University of Bristol, and are based upon the assumption that the MTs are located within a single AP range. The transmit and receive positions are shown in Fig.5 (a), while Fig.5 (b) shows a photo of the office environment under test.

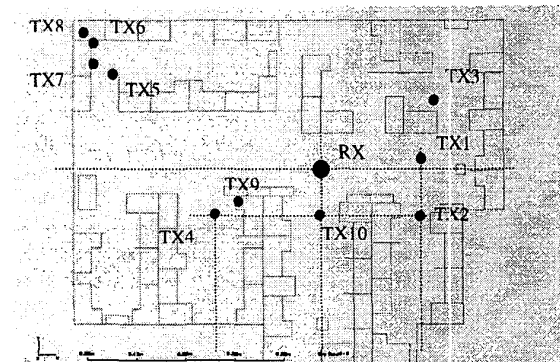


Fig.5 (a): Analysed TX and RX.

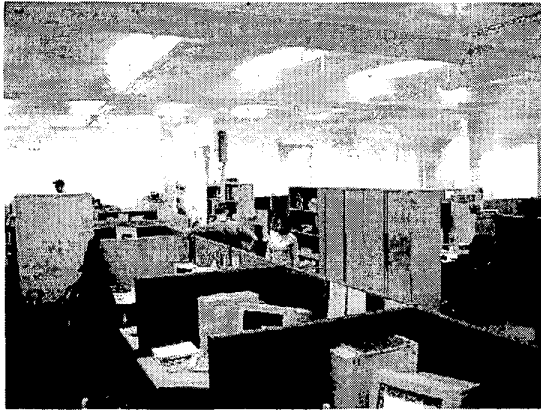


Fig.5 (b): Modern Office environment used for channel measurements.

A. Two-User Scenario

In this scenario, one MT position (TX10) with line-of-sight (LOS) is chosen to be the wanted MT, and 9 other MT positions (TX1 to TX9) are used as the interferers. The C/I is computed for this wanted MT with each of the interferers in turn and compared for the case of an omni and switched-sector circular array at the AP. Fig.6 shows the results in such scenario, in the modern office environment shown in Fig.5.

Without any power control mechanism (Fig.6 (a)), an omni-directional AP may be able to produce a certain amount of C/I, provided the wanted MT is located nearer to the AP compared to the interferer MT. The switch-sector system produces C/I ratios of up to 15dB higher than that of omni. In cases where an interferer is nearer to the AP than the wanted MT is, regardless the angular separation between the two, negative C/I is obtained.

With a power control mechanism employed (Fig.6 (b)), the switch sector system, however, produces a C/I of up to 16dB. In this case, C/I levels of the omni fall to 0dB, demonstrating perfect power control.

C/I for perfect power control largely depends on the angular separation of the wanted and interfering signals. An interferer at the back of the chosen element would be better suppressed due to the front-to-back isolation of the element.

B. Multi-User Scenario

A second analysis is conducted in a scenario such that one wanted MT is present, and 9 random MTs are added to the system one at a time, acting as interferers. C/I ratios are calculated as the interferers are added to the system. The MT positions are randomly chosen from the 10 transmit positions shown in Fig.5 (a). The maximum supportable number of users can then be observed. The following analyses have been based upon the assumption of perfect power control.

Fig.7 (a) illustrates example results of a multi-user scenario within a modern office environment, where the desired MT is located in LOS to the AP. C/I degrades as

multiple interferers are added to the system model. The rate of change is dependent upon the order in which interferer MTs are added to the system. Simulation results presented in [8] illustrate that for a packet error rate (PER) of 1%, a C/I of 12dB is required for the simplest operation mode, BPSK. In this particular case, assuming the minimum C/I supported by H/2 is 12dB, the switch-sector system is able to support up to 5 users within a single timeslot. In contrary to that, an omni-directional antenna would fail completely when one or more interferer is introduced to the channel. Fig.7 (b) shows the gain achieved by using switched sector, with respect to omni antenna. The graph clearly shows a switched-element gain of up to 21dB can be achieved.

A further simulation is conducted for the multi-user scenario using the same MT positions. This time, MT positions are chosen in random permutations and C/I is calculated for 50 sample permutations of the MT locations specified in Fig.5 (a). Once again a perfect power control has been implemented in the analysis. Fig.8 shows that assuming a minimum C/I of 12dB, a maximum of 5 users can be supported within a single timeslot. Table 1 presents the results in the form of percentage frequency of occurrence over 50 sample deployments. These two illustrations show that 54% of the time the system is able to support two or more users within a single timeslot, and that larger numbers of supportable users occur less frequently compared to 1 or 2 users.

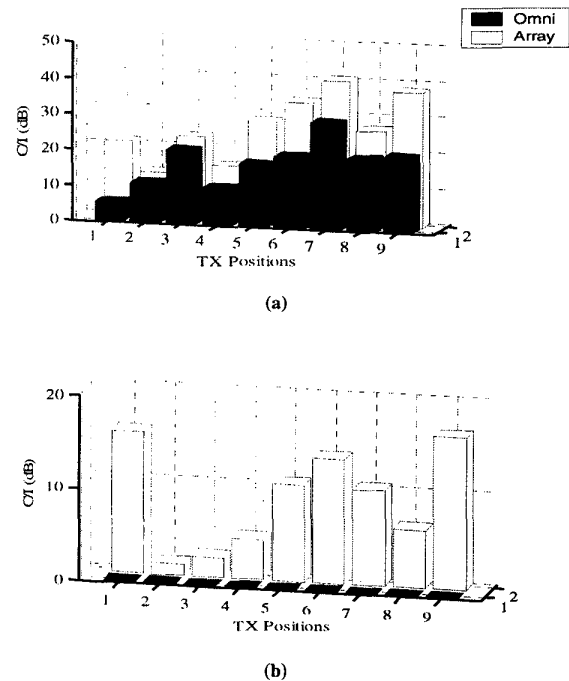


Fig.6. Wanted MT at LOS (TX1) in a two-user scenario: (a) No power control; (b) power control employed

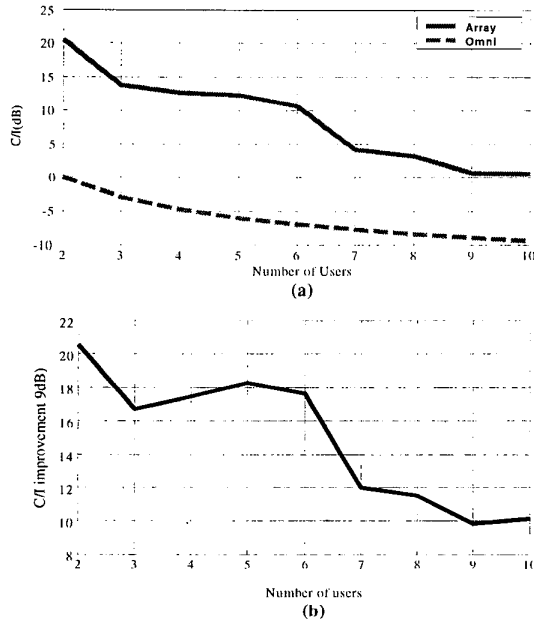


Fig.7. LOS wanted MT: (a) C/I degradation as interferers are added to the system; (b) Gain of switch-sector system with respect to omni.

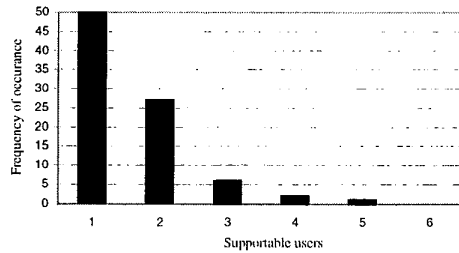


Fig.8. Random permutations of MT positions: Histogram of number of users that can be supported by the system.

Number of supportable users	Occurance (%)
1	100
2	54
3	12
4	4
5	2
6	0

Table 1: Percentage of supportable users within 50 sample deployments

IV. CONCLUSION

In this paper we have presented a measurement system for measuring the space-time characteristics of indoor environments at 5.2 GHz. An analysis of the performance of an eight-element circular array acting as an Access Point has also been presented. The C/I ratio is evidently increased

through the use of the array. We have also shown that with the assumption of perfect power control mechanism and a minimum C/I level of 12dB, 54% of the time the system is able to support two users within a single timeslot. The results presented in this paper have evidently shown that channel capacity can be increased by means of a simple switch-sector array.

C/I ratio and capacity enhancement may be increased further by using simple switch-beamforming or higher complexity adaptive antenna techniques, and the array can be synthesised to the optimum number of beams (sectors), beamwidth, and beamforming technique.

V. ACKNOWLEDGEMENT

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